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Original article

Effects of superficial heating and insulation on walking speed in people with hereditary and spontaneous spastic paraparesis: A randomised crossover study

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ABSTRACT

Objectives: Cooling of the lower limb in people with Hereditary and Spontaneous Spastic Paraparesis (pwHSSP) has been shown to affect walking speed and neuromuscular impairments. The investigation of practical strategies, which may help to alleviate these problems is important. The potential of superficial heat to improve walking speed has not been explored in pwHSSP. Primary objective was to explore whether the application of superficial heat (hot packs) to lower limbs in pwHSSP improves walking speed. Secondary objective was to explore whether wearing insulation after heating would prolong any benefits.

Methods: A randomised crossover study design with 21 pwHSSP. On two separate occasions two hot packs and an insulating wrap (Neo-G^{TM}) were applied for 30 minutes to the lower limbs of pwHSSP. On one occasion the insulating wrap was maintained for a further 30 minutes and on the other occasion it was removed. Measures of temperature (skin, room and core), walking speed (10 metre timed walk) and co-ordination (foot tap time) were taken at baseline (T1), after 30 mins (T2) and at one hour (T3).

Results: All 21 pwHSSP reported increased lower limb stiffness and decreased walking ability when their legs were cold. After thirty minutes of heating, improvements were seen in walking speed (12.2%, $P < 0.0001$, effect size 0.18) and foot tap time (21.5%, $P < 0.0001$, effect size 0.59). Continuing to wear insulation for a further 30 minutes gave no additional benefit; with significant improvements in walking speed maintained at one hour (9.9%, $P > 0.001$) in both conditions.

Conclusions: Application of 30 minutes superficial heating moderately improved walking speed in pwHSSP with effects maintained at 1 hour. The use of hot packs applied to lower limbs should be the focus of further research for the clinical management of pwHSSP who report increased stiffness of limbs in cold weather and do not have sensory deficits.

1. Introduction

Hereditary and spontaneous spastic paraparesis are progressive neurological disorders with key symptoms of spasticity and weakness observed [1,2]. These symptoms which are worse distally reflect the degeneration of central tracts within the spinal cord (corticospinal, spinocerebellar and dorsal columns) [1]. People with Hereditary and Spontaneous Spastic Paraparesis (pwHSSP) who have complicated presentations report additional signs and symptoms such as dementia or epilepsy [2] No objective difference is observed in the gait pattern of people with different presentations of HSSP [3]. Whilst health care services, such as pharmacological interventions and physiotherapy can provide some benefit, access to these are often limited [4] and hence exploring practical self-management options that pwHSSP can undertake for themselves, and incorporate into their daily lives, is important. Focus groups of pwHSSP ($n = 36$, unpublished observations) highlight that many experience slower walking and that their legs feel stiffer in cold weather, which can cause them to limit their activities. The participants reported that in cold weather they often choose to increase layers of clothing to insulate their legs because they feel that this helps to relieve the leg stiffness and ease their walking difficulties.

Previous studies have demonstrated thermal effects on nerve conduction velocity and muscle spindle excitability [5–8]. In

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pwHSSP and controls, a laboratory based study [9] explored the effects of superficial cooling and heating using a constant temperature wrap controlled by a water bath, demonstrating that cooling of the lower limb decreased walking speed. In both groups, superficial cooling had a negative effect on neuromuscular function; with a slower foot tap time, reduced rate of force generation (dorsiflexor muscles), reduced peripheral nerve conduction speed, and an increased stretch reflex size after 30 minutes in the targeted limb. In contrast, superficial warming of one lower limb increased the rate and amplitude of force generation (dorsiflexor muscle), tibial nerve conduction velocity and decreased the size of the stretch reflex. However, despite the improvements in these neuromuscular parameters no improvement in walking speed was observed in either group. It was postulated that this lack of significant improvement in walking speed with warming may be related to the fact that only the plantar and dorsiflexor muscles on one leg was heated, whilst walking is a bilateral task involving multiple muscle groups. Further, the method of warming, using a temperature controlled water bath pumping water around a cuff surrounding the shank would not be practical in a real-world setting. The results and limitations suggested that bilateral superficial heating to increase lower limb temperature should be further evaluated in pwHSSP using a more portable system, which is feasible for implementation by people within their daily lives, such as commercially available hot packs.

Passive warm up using external application of heat to increase temperatures of neuromuscular structures below the skin has been part of the physiotherapy toolbox for many years [10]. Modalities of heating can be divided into superficial and deep heating; superficial heating is provided by means such as hot packs and deep heating by modalities such as ultrasound or shortwave diathermy. Hot packs have been used as a management strategy by physiotherapists for a variety of musculoskeletal conditions including pain management [11,12] as well as by athletes as part of warm up and stretching protocols [13]. In people with neurological conditions, hot packs have been used for the management of chronic pain in people with spinal cord injury [14] but care is advised when sensory and/or circulatory deficits are evident to reduce the risk of burns [12].

The size and shape of a limb and the level of adipose tissue may affect the thermal dose achieved and should therefore be considered as an important variable when comparing effects across participants [15].

Research in the field of sports science suggests that the use of insulating garments may help to prolong any increase in skin and muscle temperature achieved with active exercise. For example, insulated track shorts have been shown to maintain temperature increases [16] in cyclists, whilst in rugby players the use of an insulated jacket has been shown to maintain core body temperature and maintain peak performance output [17].

The primary objective of this study was to explore whether 30 minutes superficial heating of the dorsiflexor and plantarflexor muscles of both lower limbs, using commercially available hot packs, would translate to improvements in walking speed in pwHSSP. The secondary objective was to explore whether the use of insulation would maintain any benefits in walking speed.

2. Materials and methods

2.1. Study design

This was an unblinded randomised cross over study design, undertaken within a university laboratory setting.

2.2. Participants

Twenty-one pwHSSP participated in the study. With 21 pwHSSP we can detect an effect size of 0.63 (α = 0.05, power = 0.8) based on previous data in pwHSSP [9]. This equates to a change in speed of 0.26 m/s, which is above the minimal clinically important difference in walking speed in people with stroke (0.1–0.2) [18]. Volunteers were recruited by responding to an advert in the UK HSP Support group quarterly newsletter. Participants were included if they:

- had a diagnosis of spastic paraparesis;
- had spasticity, graded at least one on the Ashworth Scale in both of their lower limbs;
- were able to independently walk at least 20 m with/without a walking aid.

People were excluded if they had:

- additional orthopaedic/neurological impairments;
- poor skin integrity, or reduced sensation;
- fixed ankle inversion contracture;
- a score of $\geq$ 6 on the Abbreviated Mental Test Score [19] as an indicator of those whose cognitive difficulties could interfere with the consent process or study procedures.

2.3. Data collection procedures

After providing written consent, participant's baseline characteristics (height, weight, age, gender, family history, length of symptoms, additional signs and symptoms, use of anti-spasticity medication and perceived impact of temperature on walking) were recorded. The Ashworth Score was undertaken to categorise severity of spasticity in the plantarflexor muscles [20]. People were classified as pure or complicated presentations according to genetic diagnosis and or the presentation of complicating signs and symptoms [2]. The Abbreviated Mental Test Score was used to evaluate whether additional signs of dementia were present for classification. A self-report Barthel Index recorded functional ability [21]. Walking Index for Spinal Cord Injury II (WISCI II) recorded functional walking ability [22] Skin fold thickness overlying the ankle plantarflexor muscles was measured using a Harpenden Skinfold Caliper^{TM}, (Baty International, UK) at the level of the midshank [15]. BMI was calculated from height and mass [23]. Temperature sensitivity was established by asking participants whether they experienced changes in their walking abilities in cold or warm temperatures and a yes/no response recorded.

2.4. Intervention

Participants attended two separate sessions, at least 24 hours apart. At each session two 26 $\times$ 13 cm diameter, gel-filled hot packs (Neo-G^{TM} UK) were heated in a constant temperature water bath at 45°C for a minimum of 20 minutes. Participants were seated in a supported position, whilst the hot packs were applied to the front and back of each of the participants' shanks over tibialis anterior and gastrocnemius muscles and held in place with insulating neoprene based calf wraps (Neo-G^{TM}, UK, Fig. 1). The hot packs and insulating wraps were left in place for 30 minutes, during which time the skin was visually inspected by the researcher at 5 minutes and 15 minutes. Participants were asked to report on their levels of comfort throughout.

At each session the hot packs were removed after 30 minutes heating. On one visit the insulating wraps were kept in place for an additional 30 minutes (termed insulation) and on the second visit

Fig. 1. Superficial heating set up.

the insulating wrap was removed (termed no-insulation). The order of insulation and no-insulation was randomised between participants using a computer generated randomisation programme.

2.5. Outcome measures

The standardised, validated outcome measures were carried out by the same researcher (AD) who was not blinded to the group allocation. The researcher was a physiotherapist with experience in carrying out all outcome measures with pwHSSP [9]. Measures were taken at baseline (T1), after 30 minutes of superficial heating (T2) and after 30 minutes of insulation or no insulation (T3).

The primary outcome measure was maximal walking speed (in metres per second), which is widely used and has established validity and reliability for use in people with a wide range of neurological conditions [24,25]. This was calculated based on the time taken to walk 10metres as fast as possible, from a static start. Two walks were recorded with a 1-minute rest period in between. Participants were offered a seated rest if required between tests. The mean walking speed was calculated.

The secondary outcome measures were collected in a protocolised order:

- foot tap time has been used to assess lower limb function via repetitive movements in studies evaluating the effects of temperature induced changes in people with neurological conditions including pwHSSP [7,9]. Foot tap time was measured with participants seated on a standard height chair, with their back supported and their foot placed on a rest with a height adjustable metal bar above. The bar was adjusted for each participant to the comfortable height to which they could raise the front of their foot to touch, whilst the heel was kept grounded on the floor. Participants were instructed to tap their foot 10 times as fast as possible ensuring that they touched the bar and then the floor on each tap; a practice was given on each leg. Foot tap times for both legs were recorded three times, and averaged for each leg. The foot tap time for the self-reported most affected lower limb, was used in data analysis;
- room, skin and core temperatures were recorded at each time point. Room temperature and skin temperature were measured using type-t thermocouples (BAT-10 Physitemp, USA). The room probe was attached to a pole adjacent to the seat used for the intervention and assessment of Foot Tap Time. The skin probe was placed midway between the head of fibula and tip of the medial malleolus on the posterior surface of the shank on the self-reported most affected leg. Tympanic membrane temperatures (Omron, MS 510-E2, Netherlands) was used to estimate core temperature [26]. Room temperatures were collected to monitor ambient temperatures. Skin and core temperatures were recorded to examine whether superficial heating had local or central effects. Skin temperature has been used to assess the effect of thermal interventions in healthy controls and people with neurological conditions [9,27,28].

2.6. Data analysis

Results were summarised descriptively, and the standardised mean difference was calculated. Tests of normalisation (Shapiro–Wilks) were carried out and established that all data was normally distributed. Changes in outcome measures were determined using a between groups repeated measures analysis of variance with factors being TIME (pre and post intervention) or INSULATION (insulation or no insulation). If indicated, post hoc paired t tests explored the change in scores across time points for the insulated and non-insulated conditions. Results were taken as significant if $P < 0.05$.

3. Results

3.1. Baseline characteristics

Twenty one pwHSSP were assessed, Table 1. All participants reported sensitivity to temperature, with cold having a perceived negative effect on lower limb stiffness and walking ability. Walking was affected in all participants with the majority requiring a walking aid, orthoses, or assistance to walk as described by the WISCI II (Table 1). Further, overall functional ability was limited in the majority of participants as described by the Barthel index (Table 1). Spasticity was present in both lower limbs in all participants with a minimum of grade one Ashworth observed bilaterally (Table 1).

3.2. Temperature

Baseline room temperature and core temperature did not vary significantly between the two visits (insulation and removal of insulation conditions), Table 2. There was also no significant difference for either room or core temperature at T1, T2, or T3 for either condition.

Table 1
Background and clinical characteristics of pwHSSP.

Clinical characteristic	pwHSSP
Gender	12 female 9 male
Age (years)[a]	51.2 ± 12.05
Time since diagnosis[a]	13.4 ± 7.8
Length of symptoms (years)[a]	25.2 ± 16.5
BMI (kg/m^2)[a]	24.4 ± 3.18
Calf skin fold thickness (mm)[a]	7.7 ± 4.37
Antispasticity medication	Baclofen (5), Dantrium (1), Tizanadine (1)
Ashworth[b]	2 (1–2)
Abbreviated Mental Test Score[b]	9 (6–10)
Barthel[b]	90 (75–100)
WISCI II[b]	17 (16–19)
Self report sensitivity to temperature (yes/no)	21 Y

[a] Data are mean ± SD.
[b] Data are median and range.

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Table 2
Temperature, walking speed and foot tap time at baseline (T1), post 30 minutes superficial heating (T2) and following insulation or no insulation (T3).

Measure	Insulation (I)/No Insulation (NI)	T1: baseline	T2: post heating	T3: post I/NI
Walking speed (m/s)	I	0.65 ± 0.37	$0.72 \pm 0.39^{**}$	0.71 ± 0.38
	NI	0.6 ± 0.33	$0.72 \pm 0.35^{**}$	0.69 ± 0.34
Foot tap time (s)	I	11.73 ± 6.01	$9.09 \pm 3.43^{**}$	9.09 ± 3.39
	NI	10.94 ± 3.83	$8.71 \pm 3.37^{**}$	9.18 ± 3.19
Skin temperature (°C)	I	29.07 ± 1.07	$34.25 \pm 1.26^{**}$	$30.90 \pm 1.48^{**}$
	NI	29.03 ± 2.36	$34.05 \pm 1.53^{**}$	28.81 ± 1.58
Room temperature (°C)	I	21.84 ± 1.26	22.09 ± 1.40	22.1 ± 1.47
	NI	21.73 ± 3.61	22.0 ± 1.40	22.36 ± 1.36
Core temperature (°C)	I	36.23 ± 0.39	36.10 ± 0.45	35.9 ± 0.53
	NI	36.1 ± 0.37	36.3 ± 0.37	35.98 ± 0.51

Date are mean ± SD significance at.
** $P < 0.001$.

Changes in skin temperature are shown in Table 2. There was a significant TIME × INSULATION interaction ($P < 0.001$) and a significant effect of TIME ($P < 0.001$). Post-hoc analysis of the change in temperature across TIME demonstrated that after 30 minutes application of hot packs there was a significant increase in skin temperature of 5.1°C ($P < 0.001$). With removal of the insulation skin temperature decreased by 5.2°C, whilst it decreased by 3.3°C when the insulation remained in situ ($P < 0.001$).

3.3. Walking speed

Changes in walking speed can be seen in Table 2. There was no significant difference in walking speed at T1 between the two visits. At T2 compared to T1 walking speed improved by an average of 12.2% over the two visits (effect of TIME $P < 0.001$); an average effect size of 0.18. At T3 walking speed remained significantly quicker than baseline ($P < 0.001$) however there was no difference in effect between insulation and no insulation conditions.

3.4. Foot tap time

Changes in foot tap time can be seen in Table 2. There was no significant difference in foot tap time at T1 between the two visits ($P > 0.05$). At T2 compared to T1, foot tap time decreased by an average of 21.5% over the two visits (effect of TIME $P < 0.001$), indicating quicker foot taps; an average effect size of 0.59. At T3 foot tap time remained significantly quicker than at baseline (9.9% above baseline, [$P < 0.001$] but there was no difference in effect between insulated and no insulation conditions).

4. Discussion

This study demonstrated that the application of hot packs and an insulating wrap to the lower limb for 30 minutes improved walking speed and foot tap time in pwHSSP. The improvements in walking speed were maintained at one hour following removal of the hot-packs. Further, this study found that continuing to wear insulation after the first 30 minutes was not necessary to maintain the improvements in walking speed.

In line with previous epidemiological studies of this population [29–31], 67% ($n = 14$) of participants had a genetic diagnosis and or family history of HSSP; 76% of participants ($n = 16$) had a pure and 34% ($n = 5$) complicated presentations. No exclusion was made on the basis of presentation as a previous study has reported no differences in the gait pattern in different presentations [3]. In comparison to a previous population study, the participants in this sample seemed more severely affected with 76% of participants using walking aids (Table 1) compared to 28% [32]. Further, the walking speed of this group was low (0.64 ± 0.35 m/s) in comparison to previous reports 0.96 m/s [25] or 1.22 m/s [33]. The observed low walking speed is significant as low walking speeds in community dwelling older adults are reported to be predictive of disability, falls and adverse health events [34] Van Kan et al., 2009. The results observed may therefore be more applicable to pwHSSP who have a slow gait speed and use walking aids.

The walking speed and foot tap time of pwHSSP is significantly lower than that of healthy participants [9,33]. Limitations in walking speed have been reported to relate to the characteristic impairments of spasticity and weakness observed in pwHSSP, which can affect both proximal and distal lower limb musculature [3,25,33,35]. In this study, all participants also reported sensitivity to cold which they perceived to negatively affect their walking. This may reflect a recruitment bias with people having cold related difficulties in walking responding to advertisements.

In this study, the researcher who collected outcome measures was not blinded to the group allocation of the participants and the results should be interpreted in this context. A control group who wore insulation only but did not receive heating was not included in the current project but could be considered in future studies.

Skin temperature of the participants in this study increased by an average of 5.1°C over the 30 minute period of superficial heating. Whilst this was less than in a previous study of pwHSSP by the authors (mean increase 9.8°C) [9], the observed changes in average foot tap time were comparable between the two studies (21.5% and 23.4% respectively). This study showed a statistically significant effect on walking speed which was not seen in the previous study despite positive effects on underlying neuromuscular impairments [9]. These differences may relate to the bilateral as opposed to unilateral method of warming used. The increase in walking speed was moderate at 12.2%, an average effect size of 0.18. Whilst the effect size is small, it is similar in magnitude to the effect size seen with bilateral functional electrical stimulation of the common peroneal nerve in this patient population [36]. It is postulated that the improvements in walking speed are likely to relate to the effects of heating on the neuro-muscular impairments in the lower limb including limb stiffness and spasticity, muscle weakness and nerve conduction speed [9]. The relative impact of each of these impairments remains unknown and is an important area for future research.

People with HSSP reported that their walking is slower in cold weather. This study was carried out over the summer months with a room temperature of 21.5–21.9°C; no attempt was made, using fans or other means, to reduce the air temperature to cool the limbs. With a cooler ambient temperature, it may be that the improvements in walking speed and foot tap time and the effects of retaining insulation could be more marked. Future studies could further elucidate this by incorporating active cooling of the lower limbs or the use of a cooling chamber.

This study used a superficial thermocouple to record skin temperature. The decision not to use intramuscular temperature monitoring could be seen as a limitation; however superficial skin temperature measurement has been reported to be representative of changes at deeper tissue levels [27]. Further, recent studies using mathematical modelling to estimate deeper temperature changes with systems of non-invasive skin temperature measures, also suggest that changes in skin temperature reflect changes in deeper tissue levels [28].

A hot pack is described as superficial form of heating and criticisms reflect the challenges of knowing how deeply the thermal dose is delivered. The results of this study and previous studies [9,37,38] suggest that there is transference of heat to deeper neuromuscular structures. The amount of overlying adipose tissue is a potential confounder in studies using thermotherapy which measure skin temperature with those with higher skin calliper readings showing less transfer of heat to deeper tissues [15]. In this study, pwHSSP were found to have similar skin calliper measures to a previous study (current study 7.7 ± 4.3 mm compared to 8.5 ± 2.4) [9], which reported pwHSSP to have significantly lower levels of lower leg adipose tissue compared to healthy controls. Lower levels of adipose tissue are also reported in other neurological conditions such as cerebral palsy [39].

To incorporate the use of superficial heating within people's daily lives a number of factors need further consideration and should be the focus of future research. For instance, in this study the hot packs were heated in a water bath to ensure an even distribution of temperature throughout the pack. Further studies are needed to evaluate the safest method of implementing superficial heating within a home environment. This study evaluated a single episode of superficial heating, longer-term studies are needed to evaluate and ensure no adverse effects of repeated application of hot packs. Product design needs to also be considered if the use of superficial heating is to be used on an ad hoc "out and about" approach. Finally, whilst this sample was comprised of pwHSSP, it is possible that this approach may be beneficial in other neurological conditions such as stroke or incomplete spinal cord injury, who experience similar neuromuscular impairments; this should be explored.

Insulation did not show an added benefit in this study despite a temperature difference between the two conditions with a greater drop observed in skin temperature when insulation was removed. The possible benefit of insulation to prevent a limb cooling down in cold weather was not evaluated in this study. Given that walking speed and measures of neuromuscular impairment have previously been shown to deteriorate as the limb gets colder [9], real world evaluation of this effect should be explored. The material used for insulation may also be important to consider; this study used a Neo-G™ calf wrap, which is made of mixed fibre material including neoprene; a denser thicker material may have greater effect. Any changes to the insulating wrap, however, would have to first consider the feasibility of pwHSSP donning and doffing the wrap. In this study the participants reported the Neo-G™ wrap easy to don and doff and to incorporate with orthoses such as Functional Electrical Stimulation or Ankle Foot Orthosis.

5. Conclusion

This study demonstrated that bilateral 30-minute application of gel-filled hot packs over tibialis anterior and gastrocnemius and an insulating wrap resulted in a small, but statistically significant improvement in walking speed and foot tap time in pwHSSP. The increase in walking speed continued to be significantly improved over baseline at one hour. Continuing to wear the insulating wrap for the second 30 minutes had no effect on the sustained improvement in walking speed. Further studies are needed to explore the use of superficial heating over longer time periods and within a community environment. The prevention of limb cooling in colder weather should also be explored to prevent perceived deteriorations in walking ability and muscle stiffness.

Ethical approval

Ethical approval was provided by South West Cornwall and Plymouth Ethics Committee (HS13/14-105).

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Disclosure of interest

The authors declare that they have no competing interest. Neo-G™ supplied the hot packs and insulating wraps. Neo–G™ had no involvement in the design or undertaking of this study.

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